Nuclear Reactions on Unstable Nuclei and the Surrogate Reaction Technique

Meeting Report for Nuclear Physics News International

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February 29, 2004

Determining reaction cross sections on short-lived nuclear species is a major challenge for nuclear physics and nuclear astrophysics. Many of these nuclei are too difficult to produce with currently available experimental techniques or too short-lived to serve as targets in present-day set-ups. Some nuclear reactions will remain immeasurable even at upcoming and planned radioactive beam facilities. It is therefore important to explore alternative methods for determining reaction cross sections on unstable nuclei.

Indirect approaches for studying nuclear reactions were the focus of the recent workshop 'Nuclear Reactions on Unstable Nuclei and the Surrogate Reaction Technique,' held at the Asilomar Conference Grounds in Pacific Grove, California, January 12-15, 2004. The meeting attracted about 60 participants from the international nuclear structure and reaction communities. It was organized by physicists from Lawrence Livermore National Laboratory, with the assistance of an international advisory committee that included scientists from universities (MIT, Michigan State University, and Ohio University) and research laboratories (Argonne, Livermore, Los Alamos, Oak Ridge, TRIUMF in Canada, and the Commissariat à l'Energie Atomique (CEA) in France). Funding for the workshop was provided by N Division, Lawrence Livermore National Laboratory.

The three and one-half day meeting consisted of plenary talks, parallel sessions, and working group discussions. Nuclear astrophysics, stockpile stewardship science, transmutation of nuclear waste technology, and nuclear structure physics were identified as the primary areas that will benefit from new nuclear-reaction information. Workshop participants reviewed the status of current experimental, theoretical, and computational tools available for the study of nuclear reactions. The state-of-the-art in transfer-reaction theory, level-density calculations, pre-equilibrium reaction studies, etc. was discussed and opportunities at radioactive beam facilities were outlined. The ANC (Asymptotic Normalization Coefficient) method, which has been applied to peripheral capture reactions in recent years, was presented as an example of an indirect technique for determining reaction cross sections. The workshop participants also learned about a new program of indirect nuclear spectroscopy studies at Oak Ridge, which employs radioactive ion beams to carry out (d,p) reactions in inverse kinematics.

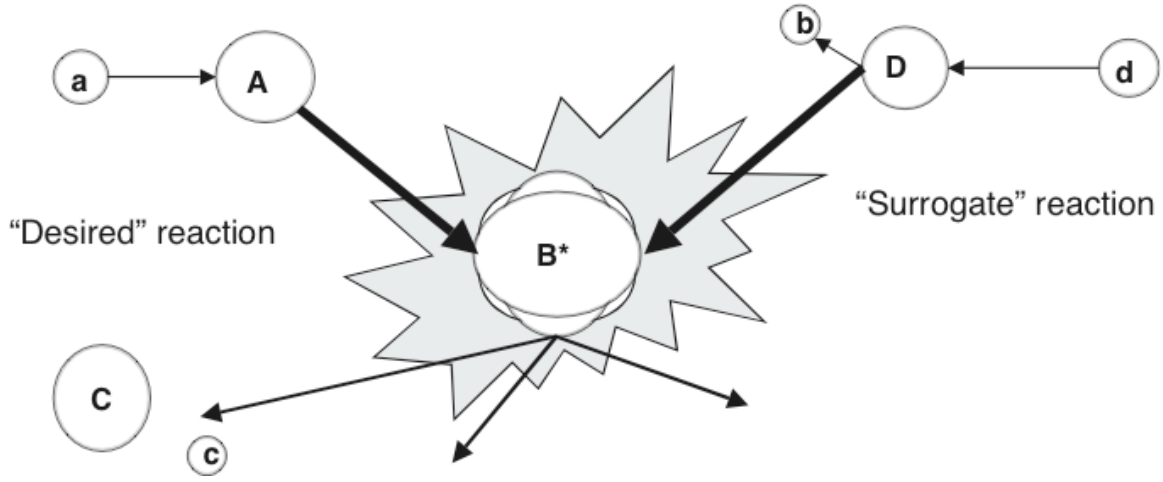
At the center of the discussions was an indirect method for obtaining cross sections for a certain class of nuclear reactions (see sidebar 'Schematic representation of the Surrogate-reaction technique). The method, in a simplified form, was used in the 1970s to extract (n,f) cross sections on actinide nuclei [J.D. Cramer and H.C. Britt, Nucl. Sci. Eng. **41**,177 (1970); H.C. Britt and J.B. Wilhelmy, *ibid*. **72**, 222 (1979)] and to study (n,p) reactions in the mass-90 region. More recently, the data for the actinides were carefully reanalyzed [W. Younes and H.C. Britt, Phys. Rev. C **67**, 024610 (2003), *ibid*. **68**, 034610 (2003)] and some test experiments were carried out to explore the method in the rare earth region. These studies were critically examined at the workshop. Working groups were formed to discuss possible applications and practical limitations of the Surrogate technique, to explore various technical issues associated with implementing the method, and to develop strategies for making progress.

The consensus at the meeting was that reactions on unstable nuclei are very important and that indirect methods will play an essential role in their study. The Surrogate approach was recognized as a potentially very useful – and in some circumstances the only feasible – method for obtaining unknown cross sections. The need for careful studies of the method was emphasized and the importance of establishing benchmarks was stressed. The workshop participants also contemplated the future of nuclear reaction physics. In this context, attracting young researcher to the field and strengthening collaborations between universities and research laboratories were identified as important goals. Overall, the presentations and discussions at the workshop illustrated nicely that the study of reactions on unstable nuclei is a challenging field with complex and rich physics as well as important and fascinating applications.

The viewgraphs of the individual presentations, as well as further information about the meeting, can be found on the workshop web site, http://www-pat.llnl.gov/Conferences/Surrogates04/. A more detailed document, which provides an introduction into the Surrogate method and summarizes the results of the workshop, is in preparation.

This work was performed in part under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory, under contract No. W-7405-Eng-48.

UCRL-JRNL-202685



Schematic representation of the Surrogate-reaction technique. The Surrogate approach allows one to indirectly determine the cross section for a two-step reaction **a + A → B* → c + C** proceeding through an intermediate nuclear state **B***, provided that **B*** is an equilibrated 'compound' state. In the Surrogate method, the compound nucleus **B*** is produced by means of an alternative ("Surrogate") reaction, here **d + D → b + B***, and the reaction cross section is obtained by combining the calculated cross section for the formation of **B*** with the measured decay probabilities for this state. The Surrogate technique is particularly valuable when the target of interest, **A**, is short lived and a suitable Surrogate reaction involving a stable target **D** can be identified.